BorobudurEngineering Review
Vol. 03 No. 02 (2023) pp. 1-16
e-ISSN: 2777-0850

Real-Time Monitoring of a PV-Based Solar Power System in a South-Western Nigerian City using LABVIEW

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https://doi.org/10.31603/benr.8422

Abstract

Understanding what is obtainable from a PV-based solar power system is key to proper sizing of the system. Proper sizing is required to ensure reliability of the system by avoiding unnecessary discontinuity in power supply from the system. The parameters that are important for reliable supply from a PV-system are the time range available for energy delivery from the panel, time at maximum charging current and the available charging current. To determine these parameters, this work sets up a complete PV-based solar system that was interfaced with National Instrument myDAQ (NI myDAQ) and LABVIEW program for data collection for a specific period of time. The collection periods were nineteen (19) days which cut across days in September to November. The data collected are the time stamps, charging current and battery voltage. The study outcome reveals that the average time range for the delivery of energy from the solar module for those periods are 7:23 am to 5:31 pm. The average time at maximum charging current is12:31 pm. The maximum charging current recorded is 0.509 A, which is 89.3 percent of the panel's current at maximum power (Imp).

Keywords:*Real-time; PV-based; LABVIEW; NImyDAQ; Monitoring*

Abstrak

Memahami apa yang dapat diperoleh dari sistem tenaga surya berbasis PV adalah kunci untuk menentukan ukuran sistem yang tepat. Ukuran yang tepat diperlukan untuk memastikan keandalan sistem dengan menghindari terputusnya pasokan daya yang tidak perlu dari sistem. Parameter yang penting untuk pasokan yang andal dari sistem PV adalah rentang waktu yang tersedia untuk pengiriman energi dari panel, waktu pada arus pengisian maksimum, dan arus pengisian yang tersedia. Untuk menentukan parameter tersebut, pekerjaan ini membuat tata surya berbasis PV lengkap yang dihubungkan dengan National Instrument myDAQ (NI myDAQ) dan program LABVIEW untuk pengumpulan data dalam jangka waktu tertentu. Periode penagihan adalah sembilan belas (19) hari yang memotong hari-hari pada bulan September sampai November. Data yang dikumpulkan adalah stempel waktu, arus pengisian dan tegangan baterai. Hasil penelitian menunjukkan bahwa rata-rata rentang waktu pengiriman energi dari modul surya pada periode tersebut adalah 7:23 pagi sampai 5:31 sore. Waktu rata-rata pada arus pengisian maksimum adalah 12:31 siang. Arus pengisian maksimum yang tercatat adalah 0,509 A, yaitu 89,3 persen arus panel pada daya maksimum (Imp).

Kata Kunci: *Waktu sebenarnya; berbasis PV; LABVIEW; NImyDAQ; Pemantauan*

1. Introduction

The idea of harnessing solar energy (i.e. energy from the sun) was initiated by Leonardo Da Vinci in the fifteenth century and Charles Fritz was eventually able to turn sun rays into electricity in 1883 (Jordan 2010). Ever since then, several efforts have been put in place to improve the amount of energy that can be harnessed. In recent years, there has been an increase in the exploitation of solar energy globally. This has majorly been due to the ever increasing global energy demand and effort to reduce fossil fuel usage associated with conventional methods of energy generation. One major advantage of solar energy plant is that it can be set up in not easily accessible locations with less maintenance, thereby making it suitable for rural electrification. Absence of emission of pollution is also an advantage. The potential of solar resource across Nigeria ranges from 3.393 - 6.669 kWh/m^2/day (Endurance et al. 2021). The Northern part of the country has better potentials over the Southern part (Lawal et al. 2022). Just like energy from other conventional energy sources, solar energy can be used for both domestic and industrial purposes. Some of its major draw backs are that, the initial setting up cost is high and it requires a large expanse of space to generate considerable amount of energy. Despite its initial set up cost, it has been reported that the photovoltaic (PV) system has a payback period of 10.18–10.42 years if installed on a large scale basis in Nigeria (Olarewaju et al. 2021). There are majorly two ways of harnessing solar energy. The first is solar-thermal energy, in which the heat energy from the sun is concentrated to heat water to steam to drive a turbine that is connected to an electrical generator. The other one is through photo-electric effect, the basic principle behind this is the conversion of sunlight to electrical energy through a photovoltaic (PV) cell. Different cells are usually connected in series and parallel to give considerable amount of energy. These connections are usually embedded into a device called solar panel. Solar panels may also be connected in series and parallel to achieve more power. While the adoption of using solar-thermal system is low globally, the adoption of PV systems has been on the high side in recent times. The adoption rate in Nigeria has been on the increase for some times now due to the epileptic power supply in the country. Most installations in Nigeria are residential based as there are few large scale installations. Despite its nationwide adoption, there is still need for more technical knowledge to optimally harness the energy. Some of such knowledge is the percentage deliverable current, time range of supply by the solar panel and time at maximum current. These information will assist installers to carry out effective system sizing. One way to harness these information is by monitoring and recording important parameters for a sample PV system installed in the location of concern. One useful tool that engineers have been using to monitor the performance of a PV system is the Laboratory Virtual Instrument Engineering Workbench (LABVIEW).

LABVIEW is a graphical programming language designed by National Instruments (NI) for scientific and engineering data gathering and recording. The fundamental point of preference of utilizing LABVIEW is the capability of reprogramming and virtual programming (National 2022). Several popularly used lab instruments features are incorporated into LabVIEW. These features includes digital multimeter (DMM), oscilloscope and function generator. It has front panel for the end-user and block diagram for the source code. LABVIEW, when interfaced with specially designed NI devices, can be used to harness signals. It can also be used to process the harnessed signal (National 2022).

Various researchers have successfully used LABVIEW to monitor PV systems in the past. Preethi et al. (2019) used LABVIEW and arduino to monitor the real-time performance of a PV system and track the sun position to maintain maximum efficiency. The parameters that were continuously monitored are the voltage, current and light intensity on solar panel. The light intensity being measured was used to adjust the inclination of the solar panel to capture maximum light. The authors reported the success of the study in capturing the parameters mentioned and tracking the sun. However, the location of the work was not stated and the setup was used to capture a one-time data of the system and not continuous one. The data captured was only used to evaluate the performance of the developed system. Kumar and Anil (2021) used LABVIEW to monitor the voltage of a solar panel at eight different inclination angles without necessarily studying the current from the panel. The work showed the dependence of panel voltage on the inclination angle. Maulik et al. (2016) developed a LABVIEW monitoring system for PV-based solar system to capture voltage, current, temperature and light intensity using various sensors. The system was reported to work well, however, the monitoring was also not location based and the data captured was for testing purpose as the system was used to capture data for few time. Jumaat et al. (2018) developed a PV monitoring system using LABVIEW and arduino in Parit Raja, Batu Pahat, Johor. The work was carried out to monitor the output of solar panel; voltage, current, power and temperature in real time. The data from the developed system was collected three times in a day for three days. It should be noted that the quantity of data gathered can’t be relied upon to understand the energy delivery pattern of the PV system. Chinomi, Boontaklang, and Chow (2017) developed a LABVIEW program that was interfaced with a well calibrated monitoring devices to acquire and store data that are associated with PV systems. The experimental set-up acquired and stored basic electrical parameters of the system. Since the work stated that the measurement was carried out for just three hours to ascertain the functionality of the set-up, it is clear that the authors only used the set-up for demonstration. Alissa et al. (2013) used LABVIEW to simulate and monitor the PV system characteristics of the Centre de Developpement des Energies Renouvelables (CDER) in Algeria. Simulation results and measured data were compared and the comparison shows that there was a good agreement between the measured and simulation results values. Anwari, Dom, and Rashid (2011) designed a small scale PV monitoring system using arduino and LABVIEW to monitor the photovoltaic array voltage, current, ambient temperature and solar irradiane. However, this work never implemented its design to test its performance. Ahmed, Kassas, and Ahmed (2014) designed and implemented a PV-standalone monitoring system using LABVIEW to monitor environmental parameters and the associated electrical variables (voltage, current and power) in a real time manner. Results for the mentioned parameters were presented for just two days. However, two days are not enough to study the behaviour of a PV system. Out of the various works available for consultation for this study, none was recorded to emphasize on important time parameters for an installed PV systems, despite its importance in identifying daily active energy delivery period. Many of the researches only analysed data that cut across few hours, hence, no daily pattern of the measured parameters was given. Also, there is paucity of researches (in open literature) for the subject matter in locations in Nigeria. In addition to the monitoring and analysing of daily recorded real-time current and voltage, this research tends to find answers to the following questions during the period under study.

a. What is the average daily active period for current delivery for a sample PV system in Osogbo, Osun State?
b. What is the average time that maximum current is delivered to the battery?
c. What is the relationship between maximum and average daily delivered current?

The objectives of this study are;

a. to develop a LabVIEW program to perform real-time monitoring of the daily available current and battery voltage from the solar panel over a period of time using National instrument myDAQ (NI myDAQ) device.
b. to setup a complete PV-based solar system that will be interfaced with the developed LABVIEW program for data collection and
c. to analyze the data from (ii) above.

2. Materials and Method

This section presents the approach used in achieving the objectives of this research. The experiment setup is situated at the Renewable Energy Laboratory of the Department of Electrical and Electronics Engineering, Osun State University, Osogbo, Nigeria.

2.1. The monitoring system

The block diagram of the developed monitoring system is shown in Figure 1. The system includes components such as solar panel, battery, charge controller, NI myDAQ Model: USB-6212, personal computer (PC) with LABVIEW program. From Figure 1, the solar panel is connected to a 12 V, 18 Ah battery through the charge controller and monitoring devices (NI myDAQ and PC). The charge controller used is a 20 A pulse width modulation (PWM) type. A PWM controller is a DC to DC converter that has the ability to adjust its duty cycle automatically based on the state of charge of the battery. The charge controller ensures that the battery is neither overcharged nor overdischarged. National Instrument's LABVIEW myDAQ hardware and software module are well-known to be most widely used devices for capturing and processing control systems (Kos, Kosar, & Mernik, 2012). NI myDAQ is a low-cost data acquisition (DAQ) device that provides the ability to take measurements and is capable of being interfaced with many sensor applications (Chinomi et al., 2017). The NI myDAQ used for this work is shown in Figure 2.

The NI myDAQ data sheet stipulates that the maximum current it can measure is 1 A. The implication of this is that, if current above 1 A is to be measured, some manipulations must be done at the input of the device. The procedure in this work tried to avoid these manipulations, hence, a solar panel whose current at maximum power (I_{mp}) is less than 1 A was selected. A 10 W solar panel (shown in Figure 3) was selected for this work since it has an I_{mp} of 0.57 A. Similarly, the maximum analog voltage that NI myDAQ device can measure is 10 V. Unfortunately, the selected solar panel has an open circuit voltage of 22.05 V and this value is more than the device specification. In order to use the device to monitor the PV system voltage, the NI myDAQ monitors the charging voltage from the charge controller via a voltage divider circuit. A voltage divider circuit was used to divide the incoming voltage into three before connecting to NI myDAQ device. It should be noted that the choice of dividing into three was due to the open circuit voltage of the panel, which is 22.05 V. Dividing into two may allow a voltage above 10 V to get to the device. So, the voltage divider circuit was used to protect NI myDAQ device from damage. The circuit diagram for the voltage divider used is presented in Figure 4. It is obvious from Figure 4 that the circuit consists of series combination of three 10K resistors. The voltage across resistor R3 was used to feed the analogue input of NI myDAQ. The input of the voltage divider was connected in parallel with the battery and both are directly connected to the terminals provided for battery on the charge controller. The choice of such a large value of resistor for the divider's circuit is to limit the current drawn by the circuit to a very small value. The divider was designed to produce a voltage that is 33.3 percent of the DC voltage received from the charge controller. This voltage value was later multiplied by three (3) in the LABVIEW program used for simulation. This multiplication was done to record the actual value of voltage before dividing. The battery charging current was measured using the digital multimeter (DMM) input of NI myDAQ hardware. The device was interfaced with the already programmed LABVIEW software on the PC via USB cable. The PC used for this work has a 500GB hard disk, 4GB RAM intel core I5 with windows 10 operating system. The PC's properties meet the expected requirement for myDAQ device. The model name of the PC is HP proBook 4400s.

For effective monitoring of a system using LABVIEW, a program, in form of a block diagram was developed to interface with NI myDAQ device. The developed block diagram is shown in Figure 5. The developed program gets necessary data from the PV system through myDAQ device. This data was being logged into the PC as an excel file. The data recorded are the time stamps, battery voltage and charging current. The monitoring of the data being logged was occationally done through the front panel interface of the LABVIEW program. A sample of the current and voltage charts during monitoring is shown in Figure 6. It is important to note that, a load was connected to the battery (through the charge controller) to discharge it at night so as to allow the panel to charge the battery daily. The load used was a 20 W DC lamp and it was meant to securely discharge the battery at night to a voltage of 10.5 V as set on the charge controller. It should be noted that, a discharged 18 Ah battery can't be fully charged by a 10 W solar panel in a day, hence, the battery was able to absorb all available current from the panel. The monitoring was carried out from 18th of September to 4th November, 2020. Power failure is a major constraint in this part of the world. To ensure constant monitoring, an inverter-battery system was used as back up for the laptop. The battery used for back up was a 100 Ah mercury battery. Even with the back-up, long duration of power failure still affects the recordings to some extent. Due to power failure, the system was restarted intermittently several times. The indoor set up that interconnects all the components mentioned is shown in Figure 7. The only component that was outdoor is the solar panel that was installed on the roof of the Renewable Laboratory. This installation was done at the roof's inclination angle of 15 degree to the horizontal facing South direction. This direction has been reported to be the best for solar panel installation for locations in the Northern hemisphere, which Nigeria falls under (Jacob 2022).

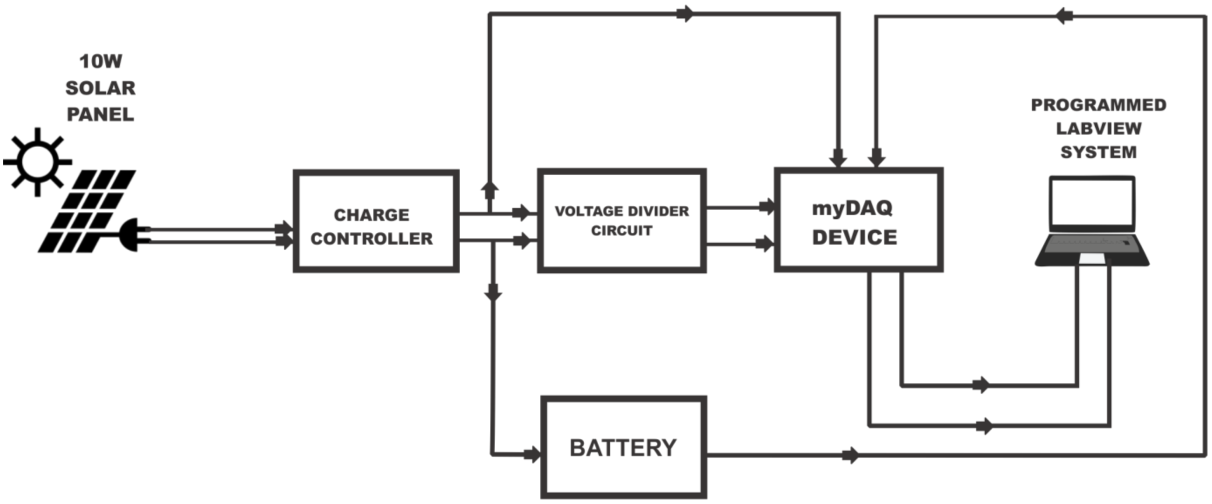

Figure 1. Block Diagram of PV based monitoring system.

Figure 2. NI myDAQ (source: Techfluent, 2020).

Figure 3. Front view of the 10W solar panel used.

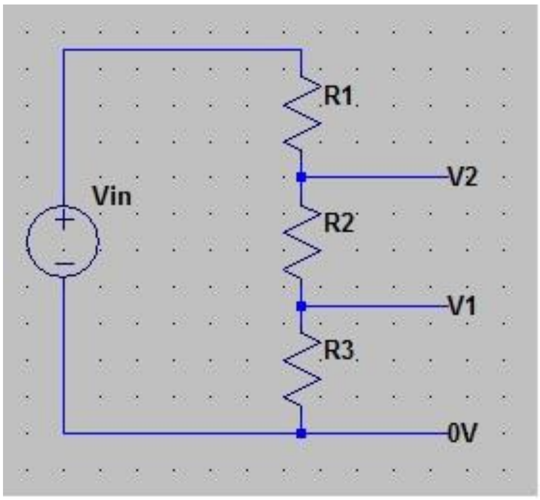

Figure 4. Voltage divider circuit.

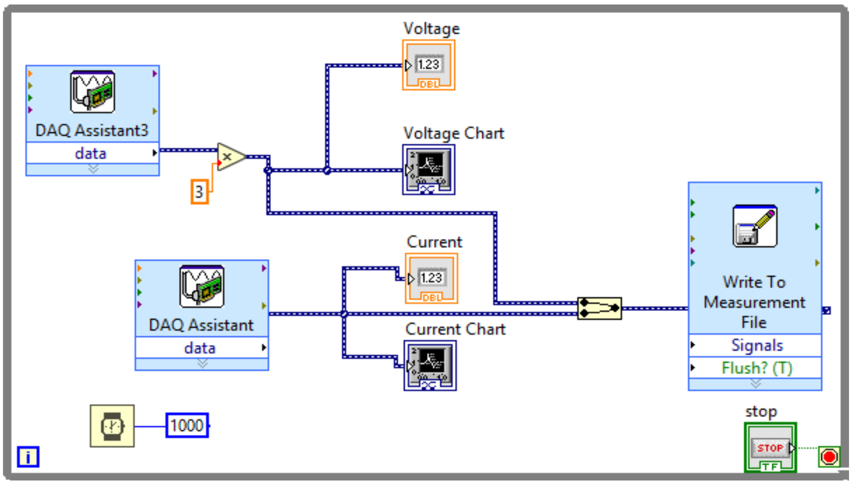

Figure 5. Block diagram of the LABVIEW monitoring interface.

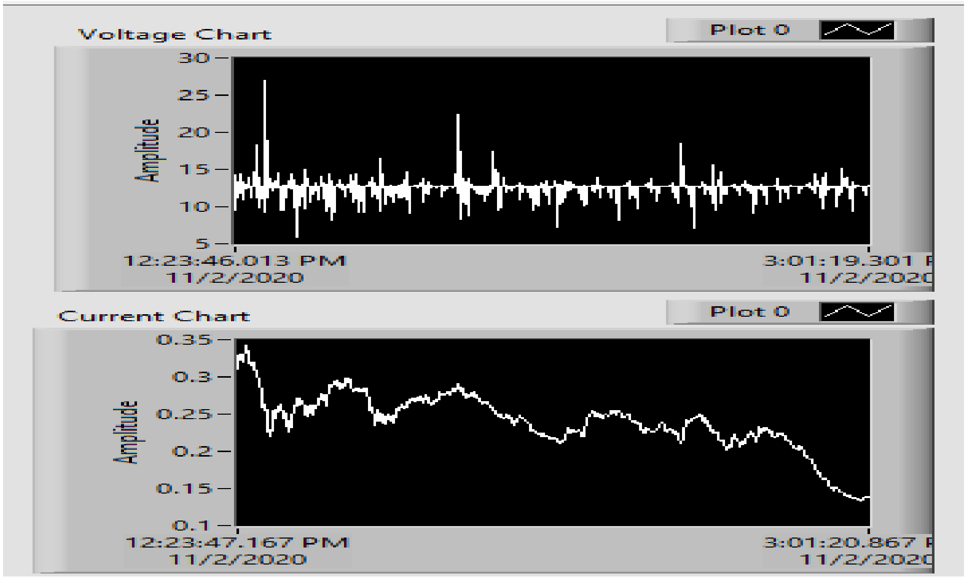

Figure 6. Front panel of the LABVIEW monitoring interface.

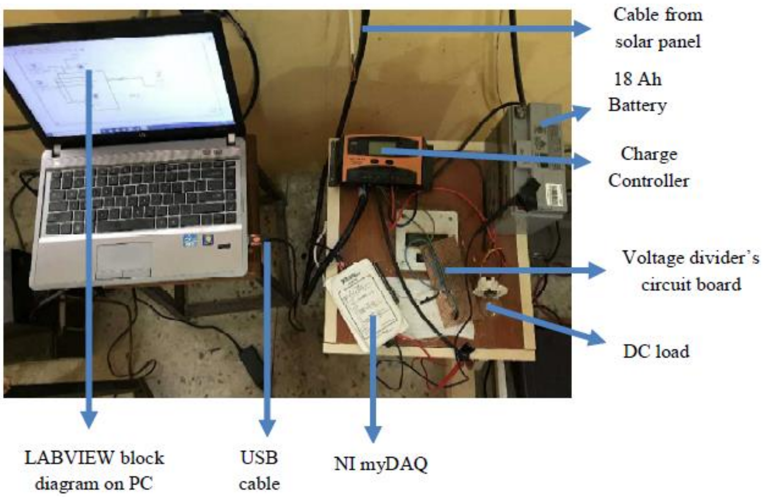

Figure 7. Complete set-up for PV-based system monitoring using LABVIEW.

3. Results and discussion

This section presents and discusses the results for the monitoring of the PV system using LABVIEW. As stated earlier, the monitoring was done from 18th of September to 4th November, 2020, but data for nineteen (19) days was fully captured and analysed. The results presented are the time range for energy delivery, time at maximum charging current, charging current and the battery voltage.

3.1. Description of the area of study

Osun State University is located at the State capital, Osogbo. It is situated between Latitude 7º41' and 7º58' North of the Equator and Longitude 4º31' and 4º37' East of the Greenwich Meridian. Osogbo shares boundary with Ilesa, Ede, Egbedore, Ikirun and Iragbiji and is easily accessible from any part of the state because of its central nature. Osogbo has a tropical dry and wet climate.

3.2. System validation

Before the collection of data, the workability of all devices used was confirmed. Therefore, extensive testing was conducted. The devices were tested and verified for accuracy. These first tests were just for short period of time. During these periods, there were series of reprogramming and troubleshooting of the system. System validation provided essential checks of the devices' response and program correctness. This procedure also aided in debugging and device settings. During this testing period, the data sheets of the devices were heavily consulted. This testing lasted for a week.

3.3. Data collection

After the validation period, real-time data collection commenced for charging current and battery voltage. After the collation of data for the period stated, it was discovered that data for nineteen (19) days were complete as power failure made the readings of other days to be incomplete or unavailable. The system was able to capture data for seven (7) days in September, ten (10) days in October and two (2) days (out of four days) in November.

3.4. Active period for energy delivery

The active time from the periods when power starts to be delivered by the PV system and when it stops was collected and shown in Figures 8 for the nineteen days. The figure also shows the time when the maximum current was delivered by the panel. The time range that was recorded as the time when the panel starts to charge the battery is 7:02 am to 7:48 am (respectively, recorded on the 18th of September and 29th of September) while the time range that was recorded as the time range when the panel stops charging the battery is 4:27 pm to 6:18 pm (respectively recorded on the 30th of September and 22nd of September). The time range during which maximum current was delivered to the battery is 10:08 am to 2:35 pm (respectively recorded on the 30th of September and 5th of October). It should be noted that it is unusual for panel to stop the delivery of energy by 4:27 pm in this part of the world. Similarly, having peak panel energy delivery at 10:08 am is also unusual. However, such unusual occurrences could happen when rain falls, which makes the atmosphere to become cloudy.

The average time range for the delivery of energy by the panel for those periods is 7:23 am to 5:31 pm. The average time that the panel delivers maximum current to the battery is 12:31 pm. Figure 9 compares daily maximum and average current. From the figure, it is obvious that the maximum current recorded ranges from 0.1281 A to 0.509 A. These values were, respectively, recorded on the 30th of September and 7th of October and they correspond to 22.47 to 89.3 percent of the current capacity of the panel. The low current of 0.1281 A was recorded at 10:08 am and as stated earlier, this can only happen on a cloudy day. The figure also shows that the daily average current ranges from 0.0412 to 0.2115 A. These values were, respectively, recorded on the 30th of September and 20th of October. It is clear that energy delivery on the 30th of September was generally poor. It can also be said that the day with the highest recorded charging current (i.e. 7th of October) was not the day with the best energy delivery. This shows that it is possible to have high peak current delivery in a day without necessarily resulting to an overall high daily average charging current. This can happen if the atmosphere becomes cloudy after attaining a good peak current. There were many days with such recorded occurrences.

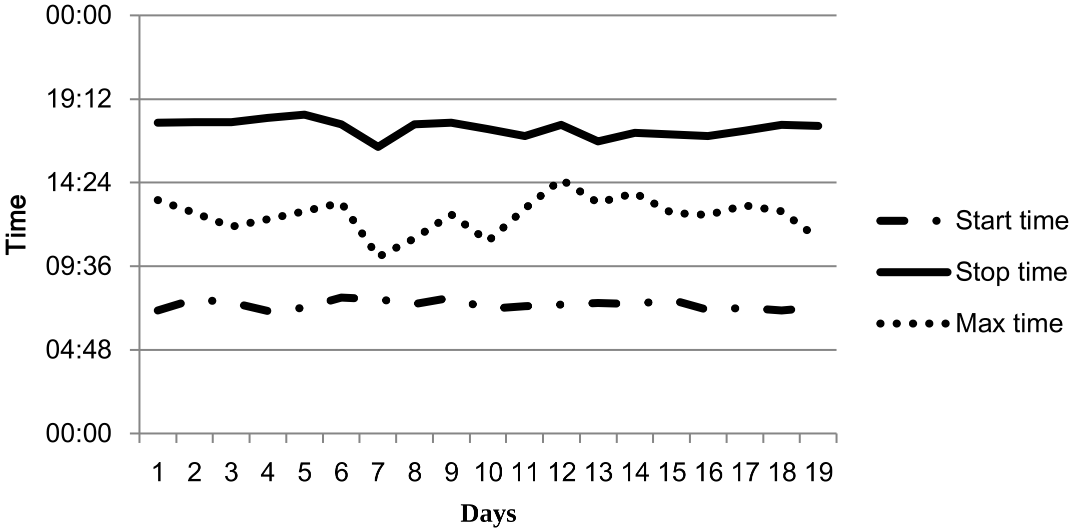

Figure 8. Important time stamps.

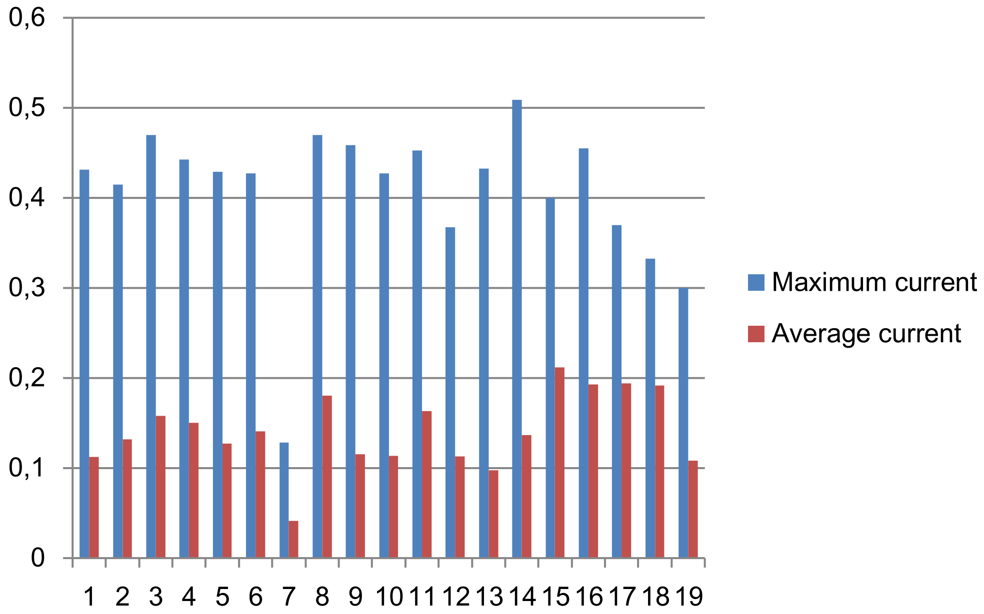

Figure 9. Comparison of maximum and average current.

3.5. Sample recorded daily current and voltage

The current and voltage for days with least and highest maximum charging current together with day with the highest average current (i.e. 30th of September, 7th of October and 20th October) are presented as samples from the monitoring carried out. Figures 10 to 12 show the charging current curves for the three days mentioned while Figures 13 to 15 show the voltage profile for the days. From the charging current profile presented in Figures 10 to 12, the charging current profile of 30th September shows the instability of the radiation received by the panel on the day, the profile of 7th October is better, but that of 20th October is the best. The area of each curve is an indication of the charging performance recorded on those days. It should be noted that the negative current recorded on 30th September was due to period that the atmosphere was cloudy. The voltage profiles of Figures 13 to 15 show that, on the 30th of September, the battery voltage in the morning and evening are, respectively, 12.01 V and 12.19 V. The voltage gained for the day was 0.18 V. Also, on the 7th of October, the battery voltage in the morning and evening are, respectively, 12.13 V and 12.42 V. The voltage gained for the day was 0.29 V. On the 20th of October, the battery voltage gain was 0.36 V as it was taken from 12.14 V in the morning to 12.5 V in the evening. The high value of the voltage gain on the 20th of October remains an indication that the battery was well charged on that day.

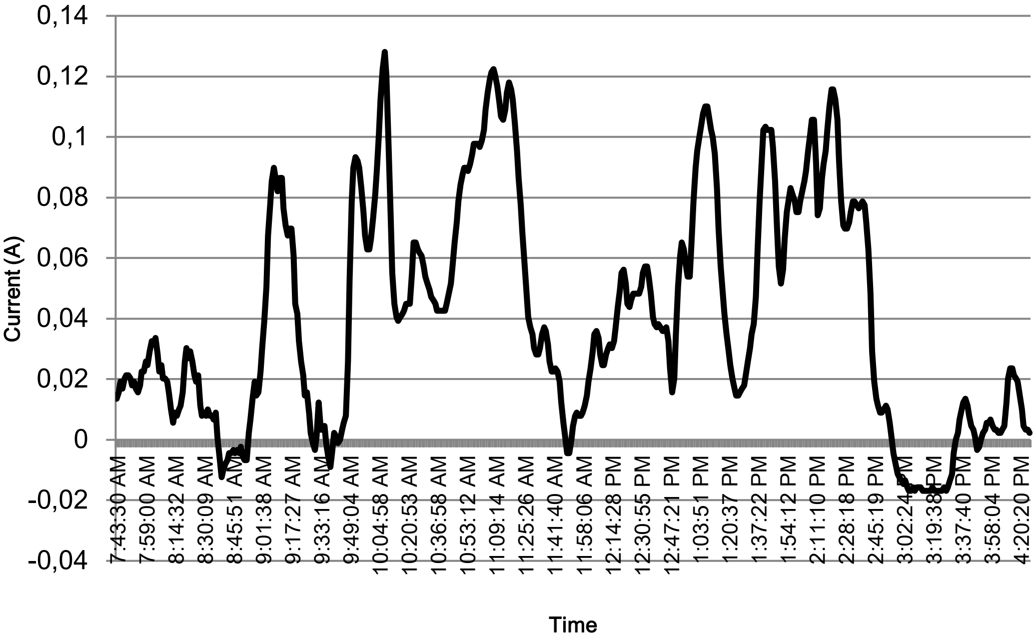

Figure 10. Recorded charging current on 30th September.

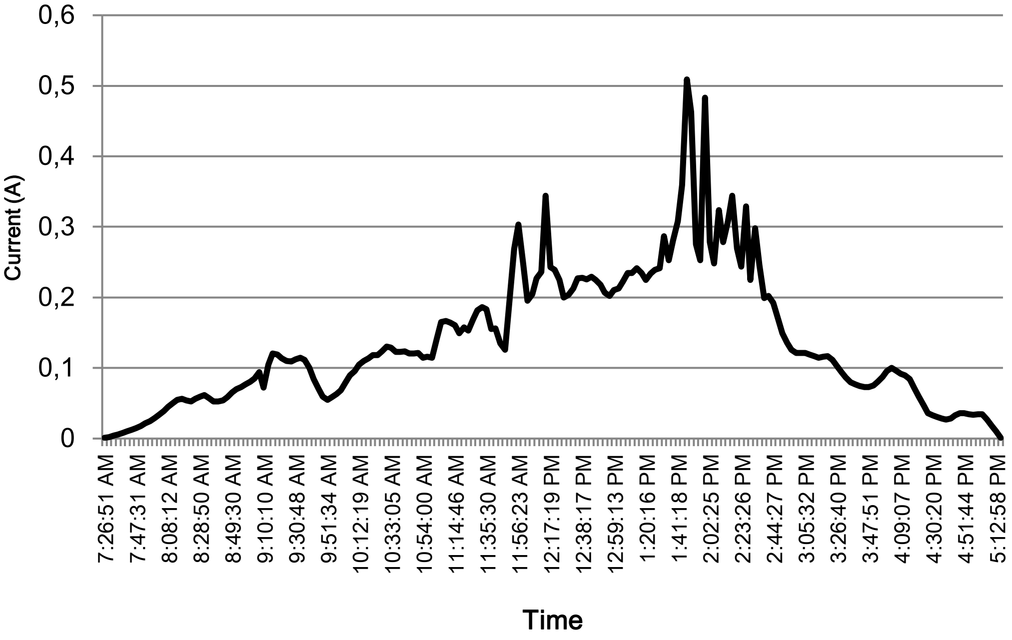

Figure 11. Recorded charging current on 7th October.

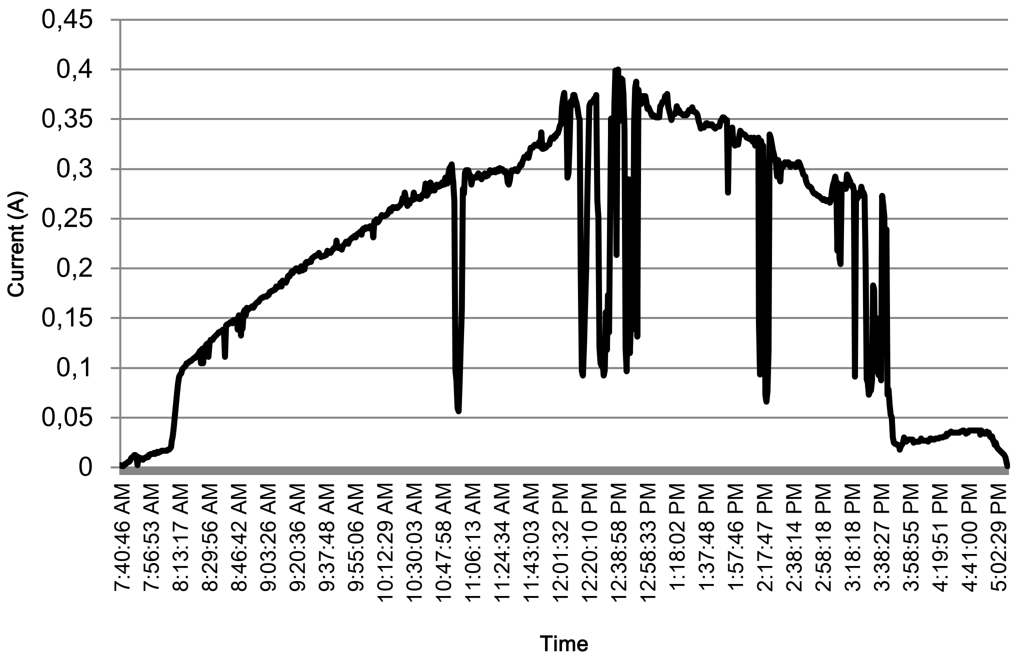

Figure 12. Recorded charging current on 20th October.

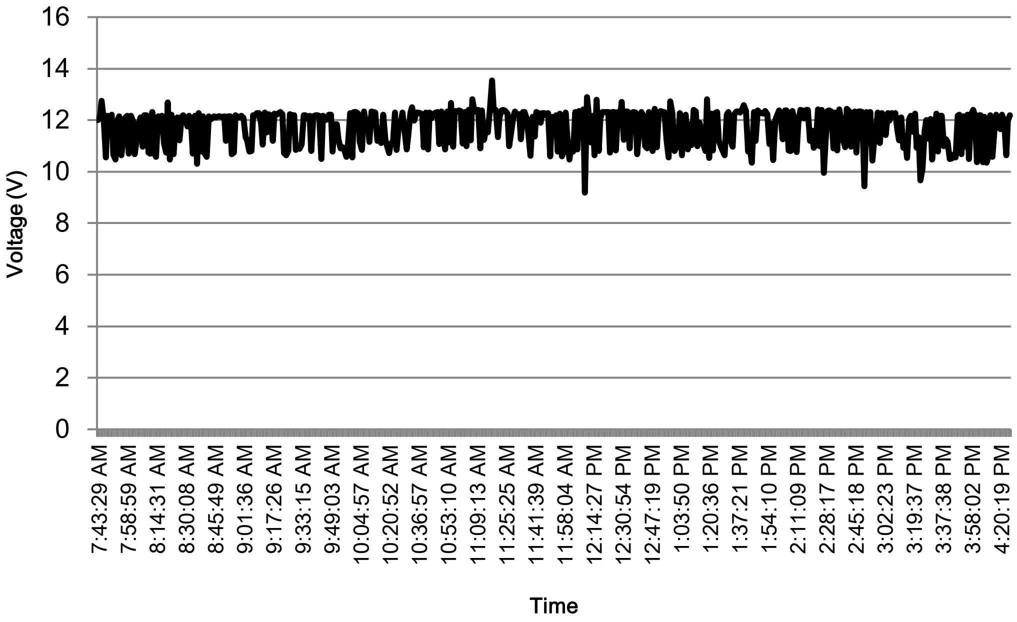

Figure 13. Recorded battery voltage on 30th September.

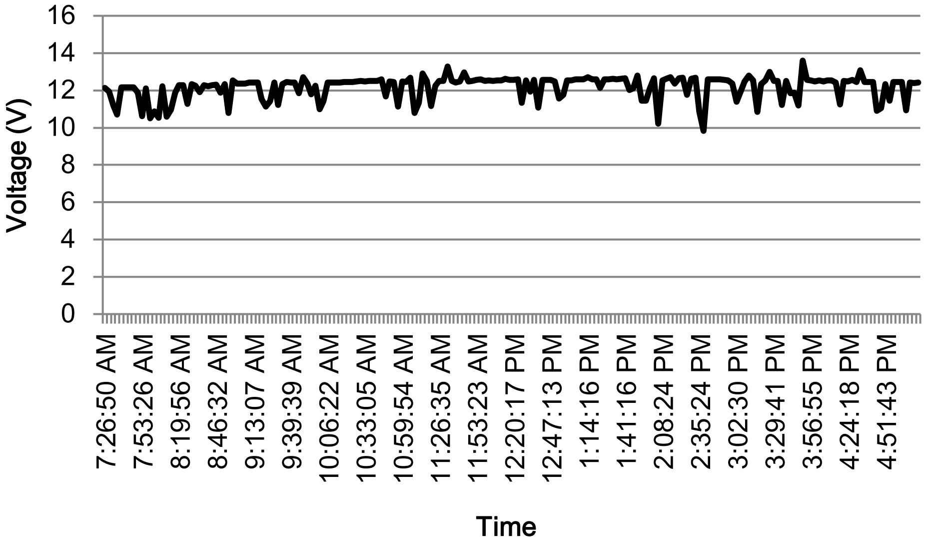

Figure 14. Recorded battery voltage on 7th October.

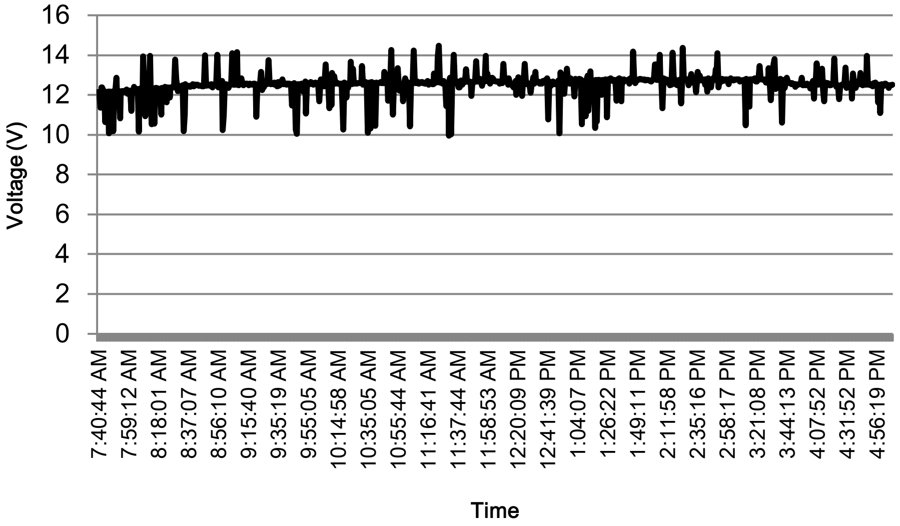

Figure 15. Recorded battery voltage on 20th October.

4. Conclusion

A complete PV-based system set-up consists of solar panel, charge controller and battery if the load to be supplied is the DC type. However, if the load to be supplied is the AC type, there will be need for an inverter to be included. The reliability of the system depends on the available charging current and voltage (from the solar panel) during the time range available for energy delivery. This study monitored a small PV-based system with the aid of NI myDAQ and LABVIEW program for nineteen (19) days to determine the time the PV system starts and stops the delivery of energy. The time when the maximum current was delivered was also determined. This study also monitored the charging current and the battery voltage during the active period of energy delivery. It should be noted that this work connected the program enabled NI myDAQ between the charge controller and the battery to monitor the stated parameters. From the results obtained, it can be concluded that:

a. The system has an approximate average charging period of about 10 hours, despite the availability of approximate daylight period of 12 hours. This is an indication that, though, the panel will have voltage across it immediately it sees daylight, no current will be delivered until the sunlight causes the panel to have a voltage above that of the battery. However, during this period of 10 hours, the delivered current varies for every time based on the level of sun radiation received.
b. The average time that the panel delivers maximum current to the battery is 12:31 pm.
c. The available sun radiation has the ability to allow the delivery of up to 89.3 percent of its current capacity on days with good radiation.
d. The daily average current delivered by the panel has great impact on the daily battery voltage profile. A high average charging current translates to high voltage margin between the voltage recorded at sunrise and at sunset.

Future work should consider monitoring that cuts across every months of the year to have a comprehensive data that describe PV-based system for the location under study. This will be able to guide installers of the system. Also, atmospheric data should also be captured side by side the voltage and current. This will allow the study of the relationship between the climate of the location and the electrical parameters.

5. Acknowledgments

The authors wish to acknowledge the Department of Electrical and Electronic Engineering, Osun State University, Osogbo, Nigeria for providing the Laboratory this work was carried out.

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